

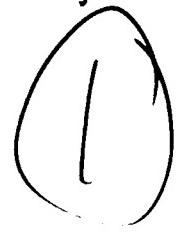
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DOT/FAA/RD-94/24

**Research and Development
Service
Washington, DC 20591**

**Vertical Flight
Terminal Operational
Procedures**



**A Summary of FAA
Research and
Development**



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July 1994

Final Report

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JUL 13 1994

Dear Colleague:

Enclosed for your information is a copy of the recently published report **FAA/RD-94/24, Vertical Flight Terminal Operational Procedures - A Summary of FAA Research and Development.**

Over the last 15 years, the Federal Aviation Administration has conducted a wide variety of tests to answer questions concerning instrument approaches to heliports. Among the approach systems investigated are airborne radar approaches, LORAN-C, microwave landing systems, heliport approach lighting, and the global positioning system. This report provides a summary of some of the more significant efforts.

Throughout the 1980's, the microwave landing system (MLS) appeared to be the only near-term option for a precision landing at a heliport or vertiport. Since that time, tremendous progress has been made on the development of the global positioning system (GPS) and MLS has been rejected. The first GPS nonprecision approach at a heliport has been commissioned in Chattanooga Tennessee and three more are planned. Plans are also being made to develop GPS precision approaches to heliports.

The expense of MLS would have limited the number of heliports and vertiports where MLS instrument approaches could have been economically justified. In contrast, due to the low life cycle costs of GPS instrument approaches, such procedures are likely to be implemented at hundreds of heliports. Early implementation at hospital heliports can provide tremendous benefits to the nation in terms of lives saved.

The implementation of GPS instrument approaches has required us to re-focus our thinking. This re-focusing is now well underway as evidenced with the commissioning of the Chattanooga GPS nonprecision approach. The publication of this report is not likely to have broad implications regarding the implementation of GPS instrument approaches. However, some portions of the work may have application to GPS instrument approaches and this document is published with this in mind.

Robert D. Smith
for Richard A. Weiss
Manager, General Aviation and Vertical
Flight Technology Program Office

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16. Abstract Common-carrier operations by helicopters are becoming increasingly routine. Prospects for their future utilization are promising as the variety of uses continues to grow and public acceptance expands. The Federal Aviation Administration (FAA) and industry are working to more fully integrate vertical flight vehicles in to the National Airspace System (NAS). Rotorcraft, including tiltrotor, tiltwing, and helicopters, are unique and each offers potential benefits that may provide relief to the delay problems being experienced throughout the NAS. Before these advantages can be fully exploited, a myriad of untested areas must be explored through research and development (R&D) activities to prove their viability. One important area is safety in terminal area operations. Safety includes such diversified subjects as approach and departure procedures, one-engine-inoperative (OEI) operations, loss of engine during critical flight phases, and landing site qualifications and capabilities. Pilot qualification, training of pilots and ground service personnel, precision approach glideslope angles, obstruction avoidance, etc., are also important safety concerns. Some of these topics have been addressed, others are currently under investigation, while others are still in the planning stages.			
This document provides a comprehensive summary of key issues identified in recently completed FAA projects concerning terminal operational procedures for vertical flight aircraft. The methodology for continued procedural development is outlined, and proposed future research and development efforts are addressed.			
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1.0 PURPOSE

This document provides a comprehensive summary of key issues identified in recently completed projects on terminal operational procedures for vertical flight aircraft. Ongoing and planned research and development (R&D) efforts are also addressed.

1.1 BACKGROUND

During the past several years, the Federal Aviation Administration (FAA) has completed numerous R&D projects dealing with terminal operational procedures. In addition, more projects are being processed and even more are in the planning stage.

The evolution of vertical flight has significantly changed over the past several decades. Early helicopters were considered nothing more than unique play-things; few practical applications were envisioned by most observers. Today, common-carrier operations by helicopters are routine. Prospects for their future utilization are promising as the variety of uses continues to grow and public acceptance expands.

The FAA and industry are attempting to integrate vertical flight vehicles into the National Airspace System (NAS). Rotorcraft, including tiltrotor, tiltwing, and helicopters, are unique and each offers potential benefits that may provide relief to the delay problems being experienced throughout the NAS.

Before these advantages can be fully exploited, a myriad of untested areas must be explored through R&D activities to prove their viability. The most important of these areas is safety. Safety includes such diversified subjects as approach and departure procedures, one-engine-inoperative (OEI) operations, loss of engine during critical flight phases, and landing site qualifications and capabilities. Pilot qualification, training of pilots and ground service personnel, precision approach glideslope angles, obstruction avoidance, etc., are also important safety concerns. Some of these topics have been addressed, others are currently under investigation, while others are still in the planning stages. Several common threads are consistent throughout the studies. They include inadequate aircraft instrumentation, undeveloped pilot skills, a lack of available off-the-shelf avionics, and a shortage of aircraft with the power available to perform desired procedures.

Various facilities and offices are involved in providing answers to these questions, including the Research and Development Service (ARD), the Flight Standards Service (AFS), the Aviation Standards National Field Office (AVN), and the FAA Technical Center's Engineering, Test, and Evaluation Service (ACN).

Since very few individuals within the FAA or industry have time to read all the research material, the FAA has prepared this summary to assist them in becoming familiar with their R&D efforts. Table 1 provides a brief summary of the projects discussed in section 2.0.

TABLE 1 SUMMARY OF COMPLETED TESTS

TEST	DOC #	DATE	PURPOSE
Airborne Radar Approach	AFO-507-78-2	1/80	Investigation of airborne weather/mapping radar as an offshore approach system.
Microwave Landing System (MLS) Approaches	FAA-AVN-200-23	5/80	Determination of approach profiles, tracking errors, and altitude loss during missed approach.
MLS Curved Paths	NASA-TM-85933	2/84	Evaluation of guidance display sensitivities and pilot acceptability.
Long Range Navigation (LORAN-C)	DOT/FAA/RD-82/78 DOT/FAA/CT-82/76	6/63	Determination of operational limitations on manually flown curved-descending and steep glide slope MLS approaches.
Helicopter GPS with Magnavox Z-set	DOT/FAA/CT-TN83/03	8/83	Collection of data and flight technical error (FTE) on LORAN-C nonprecision approaches.
Helicopter MLS Flight Test	DOT/FAA/AVN-200/25	6/86	Collection of performance data on a low-cost navigation satellite timing and ranging (NAVSTAR) global positioning system (GPS) receiver.
LORAN-C VNAV	DOT/FAA/CT-TN86/56	3/87	Development of procedural and obstruction clearance criteria to update helicopter terminal instrument procedures (TERPS) procedures.
			Development of procedures for certifying approach procedures and quantifying navigator system performance parameters.

TABLE 1 SUMMARY OF COMPLETED TESTS (Continued)

TEST	DOC #	DATE	PURPOSE
Helicopter MLS Curved Path Flight Test	FAA-AVN-500-40	7/79	Evaluation of system parameters for steep-angle and straight-in approaches utilizing a flight director.
			Establishment of standards and criteria for the design of MLS approaches and missed approaches.
Heliport Visual Approach and Departure Airspace	DOT/FAA/CT-TN87/40	8/88	Determination of airspace consumption during visual approaches and departures and verification of arrival and departure path surfaces.
Helicopter Visual Segment Approach Lighting System	DOT/FAA/CT-TN89/21	3/89	Collection of pilot performance data utilizing heliport approach lighting system (HALS).
Investigation of Flight Director and Autopilot Functions for Decelerating Instrument Approaches	DOT/FAA/CT-TN89/54	11/89	Determination of limiting factors for crosswind regulation and minimum acceptable combinations of flight director and autopilot functions for decelerating approaches.
Decision Height Windows for Decelerating Approaches in a Helicopter	DOT/FAA/CT-90/14	6/90	Determination of basic limitations to transition from a very low decision height (DH) to a steady hover at the helipad and to define a DH window.
Flight Test to Investigate Civil Certification of Sidestick Controllers for Helicopters	DOT/FAA/CT-TN90/TBD	7/90	Comparison of sidestick controllers with conventional cyclic, collective, and pedals.

Report numbers or project numbers are included to permit easy cross-referencing. The structure of this document allows the reader to become familiar with past R&D efforts, and how they will be expanded into future endeavors.

2.0 COMPLETED PROJECTS

This section incorporates a more in-depth discussion of completed R&D projects involving terminal operational procedures that were listed in table 1. Report numbers and titles are included for persons desiring access to the complete report.

2.1 AIRBORNE RADAR APPROACH FAA/NASA GULF OF MEXICO HELICOPTER FLIGHT TEST PROGRAM

Report No: AFO-507-78-2

Report Date: January 1980

Authors: Donald P. Pate and James H. Yates, PhD

Performing Organizations: Operations Research Staff. AFO-507, Flight Standards National Field Office, Oklahoma City, OK

Issue: Operational

Goals: A joint FAA/National Aeronautics Space Administration (NASA) helicopter flight test was carried out between June 1978 and September 1978 in the Gulf of Mexico to investigate the use of airborne weather/mapping radar as an offshore approach system. The specific objectives were to:

- develop airborne radar approach (ARA) procedures,
- determine weather minimums,
- determine pilot acceptance, and
- determine obstacle clearance and airspace requirements.

Methodology: The test, conducted under contract with Air Logistics, was staged from their maintenance center in New Iberia, LA. Fifteen line pilots representing a wide range of helicopter experience participated in the test. One crew member served as copilot and radar controller, providing course corrections to the second pilot who controlled the aircraft. Each pilot, hooded during the tests, made eight approaches as a controller and eight as a pilot.

The test aircraft was a twin-turbine Bell 212 helicopter. The radar was a Bendix RDR-1400 weather/mapping radar that could be operated in either beacon or primary mode with selective scan angles of \pm 60 degrees or \pm 20 degrees.

Approaches were flown to targets in a cluster of seven offshore drilling platforms located in the Gulf of Mexico. Approaches were made into the wind along routes that would provide an obstacle free approach and missed approach.

The initial approach segment was accomplished with either an arcing entry or an overhead entry. The final approach segment began at the downwind final approach point (DWFAP) located 4 nautical miles (nm) from the target rig. The aircraft slowed to 60 knots and descended to the minimum descent altitude (MDA) during this segment.

The missed approach was a climbing turn from the missed approach point (MAP) into a predetermined clear zone, free of obstacles. MDA of 300 feet and 200 feet and MAP's located at distances of 0.50 and 0.25 nm from the rigs were evaluated.

Conclusions:

APPROACH TRACKING ACCURACY

- o The final approach flight track dispersions can be described by normal distributions. The 95 percent approach envelope is funnel shaped, about 4 nm wide at the DWFAP narrowing to approximately 1 nm at 1 nm distance from the target.
- o A significant portion of the final approach azimuth error was introduced at the DWFAP by the dead reckoning procedure and was retained throughout the approach by the tendency to home on the target.
- o Once established on target, tracking was accomplished with small lateral dispersion. Little effort was made to regain the intended final approach course.
- o The mean final approach path contained approximately a 5 degree positive bias error. This error was probably introduced by the inaccuracies of the outbound procedure and the direction of turn onto the outbound leg.
- o The largest component of azimuth error was FTE.
- o Homing tracking flown under some crosswind conditions can produce a curved ground track with segments not visible by the radar set on the ± 20 degree sweep.
- o The radar system did not provide a reasonable procedure to establish and maintain a crosswind crab.

RANGE

- o A negative bias (closer to the target than assumed) was present in both primary and beacon mode range determinations.
- o The beacon mode negative bias tended to be larger than the primary mode for ranges inside 5 nm.

- o The standard deviation for primary radar mode was 0.11 nm for 2.50 nm scale, 0.24 nm for 5.00 nm scale, and 0.36 nm for 10.00 nm scale. The standard deviation increased by approximately 0.12 nm as the range scale was doubled.
- o The observed radar system error (RSE) was approximately the same as that predicted by combining the advertised 1-percent error (assumed to be processing error), delay or scan rate error, and screen resolution error at all ranges except 0.50 nm.
- o Approximately 50 percent of the negative bias error observed in the beacon mode was due to a timing delay present in the design of the ground beacon used in the test.
- o Except for the 0.50 nm range, range flight technical error (RFTE) is the dominant source of range error.
- o The radius of the 95-percent circular error probability (CEP) varied from 0.197 nm to 0.432 nm over the ranges 0.50 nm to 2.50 nm.
- o The RSE was the dominant source of error at the 0.50 nm MAP.
- o The 95-percent point for the 0.50 MAP was 0.22 nm and 0.23 nm from the target rig for primary and beacon mode, respectively.

MISSED APPROACH

- o Based on the dispersion of missed approach tracks, the one-fourth mile MAP is unacceptable.
- o The missed approach mean track of the straight-in approaches is closer to the target rig than the mean track of the offset approaches.
- o The missed approach dispersion of the offset approaches is greater than the dispersion of the straight-in approaches.
- o A greater proportion of the missed approaches initiated by aircraft from offset approaches completed their turn outside the intended clear zone than those initiated from a straight-in approach. (Aircraft must complete their missed approach turn inside the clear zone to be guaranteed lateral obstacle clearance.)
- o The point on the 95-percent envelope nearest the approach target for the offset approach is only 97 feet greater than that for the straight-in approach. That is, the minimum distance from the offset 95-percent envelope (506 feet) is not substantially greater than that of the straight-in approach (409 feet).
- o The missed approach dispersion is primarily due to MAP range accuracy, performance in execution of the turn, and the large

crosstrack dispersion of the MAP. The most significant factor is the large crosstrack dispersion at the MAP.

- o If the MAP was three-fourths of a mile from the target, the mean path and 95-percent envelope of the straight-in approaches would remain within the clear zone.

GENERAL CONCLUSIONS

- o Crew coordination is critical. Training procedures should be developed to prepare the crew for this task.
- o Differences in instruments such as the directional gyro can produce confusion. For example, if the controller's and pilot's directional gyros (DG) differ significantly, commands such as "steer 175 degrees" are inappropriate.
- o In using the radar in primary mode to avoid obstacles:
 - a. 40-degree sweeps are unacceptable for peripheral information.
 - b. 120-degree sweeps are acceptable for peripheral information, but update rate and target resolution are problems;
 - c. assuming a homing technique, certain crosswind/airspeed combinations can produce conditions in which the ground track traverses a region not presented on radar;
 - d. manual tilt and gain controls caused some difficulties; inadvertent or improper adjustments can result in lost target or significant changes in target illumination;
 - e. the present radar system display does not give a sufficient indication of the magnitude of lateral separation between the aircraft and a surface obstacle;
 - f. considerable variability exists in establishing target position, such as referencing centerline of near edge, centerline, or leading edge;
 - g. large delays are inherent in interpretation, announcement, and pilot action; and
 - h. the workload (tilt, gain, interpretation, announcement, etc.) is very high when the aircraft is close to a cluster of targets. A busy, dynamic, obstacle environment enhances the problem. Single platform approaches with low density dynamic obstacle environment produce a relatively low workload.

Recommendations:

APPROACH TRACKING ACCURACY

- o Where sufficiently accurate radio navigation (RNAV) systems are available, the DWFAP should be identified as a positive fix. To achieve improvement over the present DR/RADAR method, the 95-percent error must be less than +/- 2 nm at the 4 nm DWFAP.
- o If the DWFAP cannot be established by a positive fix, the DR/RADAR procedure should be investigated for improvements.
- o The radar system should be modified to provide a more positive method of maintaining a ground track under crosswind conditions.

RANGE

- o The radar systems should be investigated to determine methods for eliminating negative range bias.
- o Ground beacons with known design timing delays should not be used in ARAs.
- o Investigations should be carried out with existing radar range displays to determine methods for reducing range FTE.
- o Due to range error, the MAP should not be less than 0.50 nm.
- o Due to combinations of azimuth and range error, the radar should not be used to provide lateral clearance of surface obstacles within 0.50 nm or less.

MISSED APPROACH

- o To increase the probability of remaining in the missed approach clear zone, the straight-in approach could be used to clusters of rigs.
- o To reduce missed approach dispersion, the accuracy of acquiring the DWFAP should be improved and homing tracking should not be used.
- o To increase probability of lateral clearance of cluster or target, the crew should be trained to expedite the missed approach turn.
- o The crew should be trained to initiate a missed approach when the radar target is lost.
- o Range system accuracy (both crew and radar components) for establishing the MAP range should be improved.

- o The crew should be trained to initiate the minimum radius missed approach turn that is acceptable for instrument flight rules (IFR) maneuvering in the aircraft used.

GENERAL RECOMMENDATIONS

- o This type of approach requires high crew coordination. All flight crews should be provided extensive training before approaches under actual instrument conditions are made.
- o Instruments frequently referenced by controller and pilot should be closely calibrated to each other and any differences clearly noted by the crew, e.g., directional gyro.
- o If the radar is used for obstacle avoidance, it should be set in primary mode or a combination primary/beacon mode, with 120 degree sweep, and the aircraft should not "home" to the target.
- o The radar display should be modified to improve ground tracking reference, holding a crab, indication of lateral clearance, and target identification.
- o If technically and economically feasible, it would be desirable to have a system that would "lock" on target. This would reduce the airborne controller workload.

2.2 NASA/FAA FLIGHT-TEST INVESTIGATION OF MICROWAVE LANDING SYSTEM APPROACHES

Report No: FAA-AVN-200-23

Report Date: May 1980

Authors: NASA - L.L. Peach, Jr., J.S. Bull, D.J. Anderson, D.C. Dugan, and V.L. Ross; FAA - A.W. Huntington, D.P. Pate, and J.C. Savage.

Performing Organizations: NASA Ames Research Center, FAA Flight Standards National Field Office

Issue: Operational

Goals:

- o Develop acceptable angle-only MLS approach profiles.
- o Determine tracking errors.
- o Determine altitude loss during missed approach.
- o Evaluate guidance display sensitivities.
- o Evaluate pilot acceptability.

Methodology: Fourteen pilots, selected from various elements of the helicopter community, flew dual-pilot simulated instrument approaches aboard an MLS-equipped Bell UH-1H helicopter. A total of 14 flights and 140 approaches were flown. NASA or FAA observers flew on board the test aircraft on over half of the approaches.

Flight tests were conducted at the Ames Flight Systems Research Facility, Crows Landing, California. Raw data, angle-only, simulated instrument helicopter MLS approaches, landing, and missed approaches were conducted to the stolport located on runway 35 at the test facility.

A radar tracking system, a data telemetry receiver, and ground-based data monitoring and recording equipment were located at the test facility.

Flight profiles included 3-, 6-, and 9-degree glideslopes, with DHs of 50, 100, and 150 feet, respectively. DHs were established to provide a constant deceleration range from the DH to the landing site.

The final approach was conducted at a constant airspeed. Deceleration for landing was performed under visual conditions after the DH.

The subject pilots were free to select approach speeds they considered appropriate during the flight test.

Conclusions:

- o Pilot acceptability ratings indicated general acceptance of the profiles tested.
- o The use of pitch attitude to control airspeed and collective to control glideslope was the preferred pilot technique for the steep glideslope approaches.
- o Angular guidance deviation indicator sensitivity requirements for helicopter MLS approaches to heliports are significantly different from standard instrument landing system (ILS) sensitivities.
- o Pilot-recommended approach speed had mean values of 74, 64, and 58 knots for 3-, 6-, and 9-degree glideslopes, respectively. Steeper glideslopes were typically flown slower and with less airspeed variation between pilot than the 3-degree glideslope approaches.
- o The mean pilot-recommended maximum glideslope for dual-pilot "angle only" manual MLS approaches was 8.7 degrees. The maximum single-pilot glideslope recommended had a mean value of 6.1 degrees.
- o The mean minimum altitudes occurring during missed approach were 43, 77, and 118 feet for the 50-, 100-, and 150-foot DHs, respectively. The two-sigma (95 percent probability) missed-

approach envelopes were bounded by minimum altitudes of 26, 58, and 87 feet, respectively, for the above DHs.

Recommendations: Further analysis and additional flight tests will be required to fully define operational standards. The results of this flight test indicate the need to conduct helicopter MLS flight test to investigate the following areas:

- o angle guidance deviation indicator sensitivity requirements for helipads with collocated azimuth and elevation antennas,
- o the use of course tailoring to reduce pilot workload and improve tracking on "raw data" precision approaches for DHs lower than 200 feet, and
- o the use of flight director guidance to reduce pilot workload and improve tracking on manual precision approaches, particularly for DHs below 200 feet.

2.3 NASA/FAA HELICOPTER MICROWAVE LANDING SYSTEM CURVED PATH FLIGHT TEST

Report No: NASA-TM-85933

Report Date: February 1984

Authors: H.N. Swenson, J.R. Hamlin, and G.W. Wilson

Performing Organizations: NASA Ames Research Center, U.S. Army Research & Technology Laboratory

Issue: Technical/Operational

Goal: To determine the operational limitations of manually flying curved-descending and steep glideslope MLS approaches using flight director guidance utilizing three basic approach profiles that may be desirable in future MLS environments:

- o a straight-in steep glideslope approach,
- o a U-turn approach to accommodate approaches from a direction opposite the desired landing direction, and
- o an S-turn which would accommodate a lateral offset during the initial portion of the approach.

Objectives:

- o Establish the operational limitations of the profiles in terms of minimum desired segment lengths, glideslopes, and approach speeds when manually flown using flight director guidance.

- o Evaluate the profiles which appear operationally feasible using various helicopter pilots to obtain a statistical database to aid the FAA in establishing TERPS for helicopter MLS IFR approaches.

Methodology: The test aircraft was a Bell UH-1H helicopter equipped with an advanced digital avionics and flight control system, which was used to define precision approach profiles and to generate flight director commands.

The flight tests were conducted at the Ames Flight Systems Research Facility at Crows Landing, California. The MLS was representative of a typical category (CAT) II-type system which provides ± 40 degree azimuth coverage and 0 to 15-degree elevation coverage.

The facility was equipped with a radar and laser tracking system, a data telemetry receiver, and data monitoring and recording equipment used to record quantitative data to measure MLS and pilot performance.

The flight test involved 18 evaluation pilots from various elements of the helicopter community (commercial operators, corporate pilots, the helicopter manufacturers, NASA, Department of Defense (DOD), FAA, and 2 pilots from Germany). Pilot helicopter experience ranged from 350 to 8,200 hours with actual IFR time ranging between 0 and 900 hours.

Each pilot flew a total of 12 hooded approaches, 2 U-turn and 2 S-turn approaches at 6- and 9-degree glideslopes, and 2 straight-in approaches at 9 and 12 degrees to either a missed approach or landing.

Conclusions: The following conclusions were drawn from analysis of in-flight pilot ratings, pilot questionnaires, and aircraft tracking data.

- o The evaluation pilots were able to manually fly with good tracking performance the straight-in, U-turn, and S-turn approaches using flight-director guidance.
- o Approaches can be made at up to 9-degree glideslopes without degradation of the ratings and concern about high sink rates at the DH.
- o A 25- to 30-second stabilization time between any two maneuvers was required.
- o For the 100-, 150-, and 200-foot DHs, the mean altitude lost during missed approaches was 31.8, 36.5, and 54.5 feet, and the mean distance to land was 1,453.0, 1,200.3, and 1,028.5 feet, respectively.
- o The approaches flown should provide a database for the FAA to develop TERPS criteria for curved-path and steep glideslope approaches.

2.4 LORAN-C NONPRECISION APPROACHES IN THE NORTHEAST CORRIDOR

Report No: DOT/FAA/RD-82/78 and
DOT/FAA/CT-82/76

Report Date: June 1983

Author: Frank Lorge

Performing Organization: FAA Technical Center

Issue: Operational

Goals:

- o Collect data on LORAN-C system errors to support decisions about the possible certification of LORAN-C for nonprecision approaches in the Northeast Corridor.
- o Obtain data on FTE associated with LORAN-C nonprecision approaches.
- o Obtain data on area propagation anomalies of LORAN signals at various points in the Northeast Corridor.
- o Obtain performance and operational data on LORAN-C signals at various points in the Northeast Corridor.

Methodology: The flight test was part of an FAA evaluation of LORAN-C for aircraft navigational guidance.

A pair of LORAN receivers (Teledyne TDL-711) were installed on board a CH-53 helicopter. One was operated in local area calibrated mode and the other in an uncalibrated mode. The availability of various LORAN signals and their accuracy were investigated. Very high frequency omnidirectional radio range (VOR)/distance measuring equipment (DME) data were also collected for comparison purposes.

Six airports in the Northeast Corridor were selected: Salisbury, Maryland; Wilmington, Delaware; Trenton, New Jersey; Allentown, Pennsylvania; East Hartford, Connecticut; and Atlantic City, New Jersey. At least 15 approaches were flown at each airport in simulated IFR conditions.

A portable tracking system was developed at the FAA Technical Center for use during the test.

Conclusions:

- o LORAN-C in the area calibrated mode met advisory circular (AC) 90-45A nonprecision approach navigation crosstrack, along-track, FTE, and total system crosstrack (TSCT) at all subject airports when using the Seneca, Nantucket, Carolina Beach triad of the group repetition interval (GRI) 9960 chain.

- FTE associated with use of LORAN-C is below the 0.5 nm limit established by AC 90-45A.
- No LORAN-C signal propagation anomaly was observed at any of the subject airports.
- The Seneca, Nantucket, Carolina Beach triad (MXY) was available at all airports tested. The Dana signal was available in the western portion of the flight test area. Use of the Seneca, Carolina Beach, Dana triad (MYZ) produced much greater errors than the MXY triad. It is anticipated that area calibration would reduce these errors. The MXY triad should be used primarily throughout the flight-test area because the Dana signal, when available, has marginal strength for accurate tracking.
- Area calibration is effective within a regional area, the extent of which cannot be determined from the amount of testing done. Accuracy decreases as distance from the calibration point increases. Also, calibration may not be effective in an area that may be nearby but has largely different propagation characteristics.

2.5 HELICOPTER GLOBAL POSITIONING SYSTEM NAVIGATION WITH THE MAGNAVOX Z-SET

Report No: DOT/FAA/CT-TN83/03

Report Date: August 1983

Author: Robert D. Till

Performing Organization: FAA Technical Center

Issue: Technical

Goals: Collect operational performance data on a low-cost navigation satellite timing and ranging global positioning system (NAVSTAR GPS) receiver when used in helicopter navigation.

Methodology: Flight tests were conducted in a Sikorsky CH-53 helicopter using a prototype low-cost GPS receiver, the Magnavox Z-set.

Four route structures were flown between July 19 and November 24, 1981 with GPS as the primary navigation guidance, without aided altitude. Three to five satellites were available for selection in the navigation solution.

More than 15 hours of radar-tracked en route flights and nonprecision approaches were flown with two-dimensional GPS derived guidance (cross-track and range to go) used as the primary navigation system.

VOR/DME waypoints provided an inflight validity check of GPS guidance.

Conclusions:

- o GPS navigation is viable with the en route, terminal, and nonprecision approach operational performance and error criteria specified in AC 90-45A.
- o AC 90-45A and the Federal Radionavigation Plan (FRP) error criteria were exceeded in some portions of the test program due to limitations of the Z-set.
- o Static data collected demonstrates the optimum accuracy and performance that can be expected from a low cost, C/A code, GPS receiver if vehicle dynamics and measurement system errors are eliminated.
- o Rotor modulation increased the acquisition time of almanac and ephemeris data.
- o Rotor modulation did not prevent satisfactory navigation.
- o The Z-set does not provide an indication when aided altitude is substituted for a satellite pseudorange in the navigation solution. Position error perturbations were not detected when a satellite was momentarily lost in a turning maneuver.
- o Aided altitude significantly improved three-satellite navigation performance.
- o The FTE is the major source of TSCT for GPS navigation.
- o Two GPS guided flights were conducted in rain and one hover was conducted during light snow. No correlation could be established with almanac collection difficulties and weather conditions. Successful satellite acquisition was accomplished under rain and snow conditions. Navigation guidance was not affected by weather conditions.
- o Multipath effects were not detected in any tests conducted.

Additional Comments/Recommendations:

- o A capability to measure GPS satellite strength must be developed.
- o User equivalent range errors (UERE) were not determined for the tests. UERE can significantly reduce the range of permissible horizontal and geometric dilution of precision values. A monitor station should be developed and established at the FAA Technical Center to monitor and measure UERE.
- o Future tests should be conducted to:

- a. determine effect of age of ephemeris data on user position errors,
 - b. expand geographical coverage of en route and nonprecision approach tests when the full complement of satellites are available,
 - c. provide guidance compensated for Z-set data latency,
 - d. examine GPS-derived vertical guidance,
 - e. examine aided or quickened guidance information to compensate for low dynamics response of the GPS receiver, and
 - f. obtain more data with three-satellite navigation and aided altitude.
- o The following tests cannot be adequately performed until the capability to measure GPS satellite strength is available:
 - a. investigate radio frequency interference (RFI),
 - b. further investigate multipath effects,
 - c. examine possible precipitation static effects,
 - d. further investigate interference of weather, i.e., rain, snow, thunderstorms,
 - e. perform rotor modulation tests, and
 - f. determine effects of future DOD changes to signal coding and signal strength during Phase II and III.
 - o In the interest of national security, the DOD has considered intentionally degrading the accuracy of GPS navigation for civil use. Future tests should be conducted to determine the effect of accuracy degradation if implemented.

2.6 HELICOPTER MLS FLIGHT TEST

Report No: DOT/FAA/AVN-200/25

Report Date: June 1986

Authors: C. Hale and P. Maenza

Performing Organization: Standards Development Branch, AVN-210

Issue: Technical

Goals:

- o Develop procedural and obstruction clearance design criteria, including final approach minima for MLS to a helipad.
- o Update Helicopter Procedures in Chapter 11 of TERPS.
- o Provide support for the prototype demonstration heliport program.

Methodology: Fifteen pilots, selected from various elements of the helicopter community, flew simulated instrument approaches using a raw data display aboard a Sikorsky S-76 helicopter. The S-76 was equipped with a Sperry Automatic Flight Control System (AFCS) and a HelCIS Flight Director with raw data displayed on a Sperry RD650A Horizontal Situation Indicator (HSI). The aircraft was certified for single-pilot IFR operations and is representative of the IFR-certified helicopters currently in use. A total of 24 procedures were flown by each of the 15 subject pilots for a total of 360 approaches and departures. Elevation angles of 3, 6, and 9 degrees were utilized for this test. The subject pilots flew all approaches single-pilot, "under the hood."

The view-limiting device used during this test was the IMC simulator series 1020. These special goggles were clouded on top and side to limit the pilot's view of the cockpit instruments. At DH, the safety pilot cleared the goggles if the subject pilot was to land or left the goggles clouded if the pilot was to execute a missed approach.

Flight-test performance parameters and navigation errors were monitored from an airborne data acquisition system. Aircraft tracking data were monitored from a ground-based radar data acquisition facility located near the helipad site.

Conclusions: Analyses of pilot ratings, pilot questionnaires, aircraft performance data, aircraft tracking data, and obstacle clearance resulted in the conclusions described below.

- o All 3-degree elevation angle approaches were acceptable. However, to efficiently decelerate and land at the pad, a ground speed of 75 knots or less was required for a 100-foot DH. All 6-degree elevation angle approaches were acceptable; however, again, ground speed should not exceed 75 knots for a 200-foot DH.
- o It was the general opinion that deceleration distances with the 3-degree approach to a 150-foot DH and the 6-degree approach to a 300-foot DH were "about right."
- o The 9-degree elevation angle approach to a 350-foot DH was generally not acceptable, although all approaches resulted in successful landings or missed approaches. The major concern was that the pilots' initial impression when making the transition from IFR to visual flight rules (VFR) was that the helicopter was too

high to make the landing pad. This normally resulted in the pilot over-correcting by increasing the rate of descent and bleeding off airspeed. Workload rating by the subjects indicated more than minimal demand on the pilot.

- Course width sensitivity for both the azimuth and elevation was acceptable.
- To avoid an excessive rate of descent and excessive deceleration distance, a maximum tailwind component should be established.
- It was the general opinion that a two-pilot crew would be desirable for all approaches flown to a heliport, and should be required to the lower DHs flown.
- Based on analyses of aircraft position data, the final approach area, final obstacle clearance surface, and missed approach surface and area, as depicted in TERPS chapter 11, should be modified to meet targeted safety levels.
- The MLS azimuth (AZ) should be used for on-course departures. The departure area should begin at the hover point and extend outward along the selected course.
- The mean altitude loss below DH occurring during missed approaches was 15.53, 21.42, and 38.63 feet for the 3-degree elevation angle at 100, 150, and 200-foot DHs; 38.63 and 55.35 feet for the 6-degree elevation angle at 200- and 300-foot DHs; and 86.80 feet for the 9-degree elevation angle at 350-foot DH. The two-sigma (95 percent probability) missed approach envelopes were bounded by minimum altitudes of 62.81, 105.14, and 137.27 feet for the 3-degree elevation angle at 100-, 150-, and 200-foot DHs; 115.53 and 179.31 feet for the 6-degree elevation angle at 200- and 300-foot DHs; and 174.84 feet for the 9-degree elevation angle at 350-foot DH. There was a noted increase in altitude loss with an increase in elevation angle. This was expected due to the higher sink rates encountered with increasing elevation angles. At specific elevation angles, the altitude loss decreased as DH decreased.

Recommendations:

- The maximum "groundspeed" for helipad approaches with elevation angle (EL)/DH combinations of 3 degrees/100 feet, 6 degrees/200 feet, and 9 degrees/350 feet should not exceed 75 knots.
- Allow raw data MLS approaches to a helipad to EL/DH combinations no lower than 3 degrees/200 feet and 6 degrees/250 feet. For lower minima, a copilot or better in-flight instrumentation is required, e.g., scheduled course width sensitivities computed by range or a flight director system, a lower minimum IFR airspeed (V_{min}), or combinations must be used.

(Note: The 6 degree/250 feet combination was not flown during this project; however, the recommendation was made based on deceleration distance.)

- Pilots should receive training on the techniques of tracking steep glidepaths and the importance of speed control and deceleration for approaches to a helipad.
- For precision approaches to a collocated MLS sited at the helipad, the azimuth course width should be set to ± 3.6 degrees. The EL course width should be set to one-third of the selected elevation angle (SEL/3) for MLS glidepaths up to 9 degrees.
- The maximum tailwind component during an instrument meteorological conditions (IMC) approach to a helipad should not exceed 15 knots.
- For all approaches below 200 feet DH or angles above 3 degrees, a two-pilot crew should be required.
- The proposed heliport final approach surface area should be measured outward and along the final approach course from the approach surface reference point (ASRP). The final approach area should be centered on the final approach course. The area should be 1,000 feet wide at the ASRP and splay outward at 5.6 degrees from the course. The width "1/2 W" either side of the final approach course at a given distance "D" from the ASRP can be found by using the formula $500 + .098D = 1/2 W$.

Note: The above approach surface area is adequate for an azimuth sensitivity of ± 3.6 degrees.

- The final approach obstacle clearance surface should begin at the ASRP and remain at ASRP elevation for 1,150 feet. The surface then begins to rise at different slope gradients depending on the approach elevation angle. The slope gradient at 3 degrees should be 34.0:1, 6 degrees should be 16.9:1, and 9 degrees should be 11.1:1.

Note: The above approach obstacle clearance surface is adequate for an elevation sensitivity of SEL/3.

- The missed approach area and surface should originate at the missed approach point and continue inward along the approach for 1,500 feet. The missed approach area should splay at 20 degrees from the intended course. The missed approach surface should rise at a gradient of 20:1.
- During a missed approach, pilots should climb 200 feet above DH on the approach heading before turning.
- The on-course departure area should be 300 feet wide at the hover point and splay outward at 5 degrees from the intended course. The

width "1/2 W" either side of the course at a given distance "D" from the hover point can be found by using the formula $300 + .088 D - 1/2 W$. The obstacle clearance surface should begin at the hoverpoint and remain at the hoverpoint elevation for 775 feet. The surface then begins to rise at a gradient of 20:1. Operations or departures protected by these surfaces should be restricted to crosswinds not exceeding 15 knots and aircraft groundspeeds not less than 65 knots..

- The minimum distance (160 feet) from the AZ antenna to the hover point from which course guidance departures were initiated should be further studied to determine if the distance can be reduced.

2.7 LORAN-C VNAV APPROACHES TO THE TECHNICAL CENTER HELIPORT

Report No: DOT/FAA/CT-TN86/56

Report Date: March 1987

Author: Michael Magrogan

Performing Organization: FAA Technical Center

Issue: Technical

Goals:

- Acquire a statistically reliable database concerning overall three dimensional (3D) LORAN-C navigator system performance.
- Develop operational procedures that will assist the FAA and airspace users in developing and certifying standard approach procedures and associated weather minimums.
- Quantify specific 3D LORAN-C navigator system performance parameters.

Methodology: Flight tests were flown under simulated IFR conditions. Each flight consisted of a series of eight approaches to the FAA Technical Center's helipad. The final approach fix was 2.0 nm from the helipad. All approaches were straight-in approach profiles. Flights were flown in VMC.

The flight crew consisted of the subject pilot, the safety pilot, and a flight technician. The subject pilot made all approaches with reference to navigation deviation information provided on his HSI. Throughout the flight, IMCs were simulated by restricting the subject pilot's field of vision.

Due to budget considerations the test was limited to 15 flight hours, 12 hours for data collection, and 3 hours for system checkout and pilot training.

Conclusions: Based on operational evaluation and the data analysis presented in the report, the following conclusions can be made about 3D LORAN-C navigator system performance.

- The 3D LORAN-C navigator performed within the limits identified in AC 90-45A for two dimensional (2D) error components of TSCT and FTE.
- The 3D LORAN-C navigator performed within the limits identified in AC 90-45A for the 3D error components vertical flight technical error (VFTE) only.
- The lack of distance information in the cockpit eliminates the ability of the pilot to cross-check his along-track position during the approach.
- Different altitude sources were used for vertical navigation (VNAV). The navigation system had its own altimeter while the pilot flew the aircraft referencing a different altimeter. Discrepancies of up to 100 feet were noted between the 2 altimeters.
- The integrity of the displayed vertical guidance was unreliable. Vertical guidance was often flagged at low altitudes.
- The TDL-711 receiver has a fixed lateral display sensitivity of 1.26 nm, full scale. This provides a sluggish, overdamped needle response and does not take advantage of the full accuracy of LORAN.
- The vertical flag appears to give erroneous and conflicting information. This flag should always be in view when the lateral flag is in view for the system as currently implemented.

Other Comments: The TDL-711 LORAN-C receiver used for VNAV flight testing is not representative of LORAN receivers that could be used for 3D approach guidance.

This flight testing was conducted with prototype avionics. Several of the vagaries noted can be attributed to this fact. If additional tests are accomplished, the work should be done with production hardware or modifications of such equipment.

2.8 HELICOPTER MICROWAVE LANDING SYSTEM CURVED PATH FLIGHT TEST PROGRAM REPORT

Report No: FAA-AVN-500-40

Report Date: July 1989

Author: Navigation Systems Section, AVN-542

Performing Organization: Standards Development Branch, AVN-540

Issue: There are no criteria in TERPS that permit procedures specialists to design MLS straight or curved-path approaches. TERPS ILS criteria have been applied to interim MLS straight-in approaches, but criteria are nonexistent for any type of curved-path approaches.

Goals:

- o Evaluate system parameters of steep-angle, straight-in approaches utilizing flight directors, precision distance measuring equipment, and full capability coupled curved-path approaches.
- o Build a database that could be used to establish standards and criteria from which procedures specialists may design helicopter MLS approaches and missed approaches.

Methodology: The test was conducted in two phases and required 150 aircraft flight hours.

Phase I - A NASA research pilot flew a UH-1H helicopter to investigate and develop:

- o basic guidance requirements for the transition from en route air traffic control (ATC) radar vectors to MLS coverage,
- o reference MLS curved approach profiles,
- o acceptable flight director display sensitivities, and
- o scheduling techniques for both approach and missed approach operations.

Phase II - Procedures developed in Phase I were validated through flight tests. This phase included 18 evaluation pilots from various elements of the helicopter community, i.e., commercial operators, corporate pilots, the helicopter industry, NASA, DOD, FAA, and two from Germany.

Test and evaluation pilots flew hooded instrument approaches from the left seat of the aircraft. Experience levels ranged between 350 and 8,200 hours, and actual IFR time between 0 and 900 hours. Thirteen of the 18 pilots had flight director experience in either fixed-wing aircraft or helicopters.

The flight test was conducted on three consecutive days. The first day consisted of briefings and familiarization of pilots with the approaches, cockpit displays, and instruments. The second and third days were test flights. Each pilot flew a total of 12 hooded approaches. They included two U-turn and two S-turn approaches at 6- and 9-degree elevation angles, and two straight-in approaches at 9 and 12 degrees to either a missed approach or a landing. Six approaches were flown the second day and six the third.

A final approach segment of 2 nm was required independent of the elevation angle. Recommended approach speeds were 70, 65, and 60 knots for the 6-, 9-, and 12-degree elevation angles, respectively.

DHs for these elevation angles were 100, 150, and 200 feet above ground level, respectively. This gave a constant deceleration range of 1,000 feet from the DH to the landing site.

Conclusions:

- o The pilots were able to capture the desired approach path with little overshoot from the 30- and 60-degree intercepts.
- o A straight segment of 25-30 seconds between maneuvers is necessary to stabilize the helicopter.
- o The approaches can be made at up to 9 degrees elevation angle without degradation of the pilot's handling qualities ratings.
- o The 100 and 150-foot decisions heights were acceptable for the 6- and 9-degree approaches, respectively.
- o The 6- and 9-degree U-turns and S-turns, ± 6 standard deviation screening contour, exceeded the vertical and lateral deviations used in the test.

Additional Comments:

- o The general consensus was that all the profiles tested would be appropriate for dual-pilot operations. For single-pilot operations, they recommended that the glideslopes be limited to a value between 7 and 8 degrees.
- o The consensus was that the approach profiles were operationally acceptable except the 12-degree straight-in approach. (Pilots found the 12-degree approach to be more difficult than the others. This was attributed to the lack of collective control authority to correct to the desired flight path when the aircraft was above the glidepath.)

2.9 HELIPORT VISUAL APPROACH AND DEPARTURE AIRSPACE TESTS

Report No: DOT/FAA/CT-TN87/40

Report Date: August 1988

Authors: Rosanne M. Weiss, Christopher J. Wolf, Maureen Harris, and James Triantos

Performing Organization: FAA Technical Center

Issue: Technical

Goals:

- o Determine the airspace consumed during visual approaches to a heliport.
- o Verify dimensions for the current Heliport Design Guide's visual approach path surfaces and determine possible modifications to these surfaces.
- o Determine the airspace consumed during visual departures.
- o Verify dimensions for the current Heliport Design Guide's visual departure path surfaces and determine possible modifications to these surfaces.
- o Specific issues to be considered are the angle of approach/ departure surface, width of the surface, surface length, and alignment of the surface.

Methodology: Flight activities were conducted using a Sikorsky S-76, a Bell UH-1, and a Hughes OH-6. A total of 1,217 data runs were completed.

A cross section of pilots from the private sector, military, and FAA were used during these tests. S-76 pilot experience ranged from 181 to 7,300 helicopter hours, UH-1 experience ranged from 400 to 7,300 hours, and OH-6 experience from 1,200 to 3,200 helicopter hours.

Each pilot flew each approach and departure angle at least three times during a flight. In addition, pilots were allowed to fly six approaches and six departures using any angle of their choice. This yielded a total of 15 approaches and 15 departures for each pilot. Five of each were curved-path approaches.

Three different approach elevation angles (7, 8, and 10 degrees) and three different departure elevation angles (7, 10, and 12 degrees) were utilized.

Except for the pilot choice procedures, the safety pilot told the subject pilot when to begin the approach and from which point to start the departure.

Following each maneuver, the safety pilot took the controls while the subject pilot rated the maneuver using a modified version of the Cooper-Harper rating scale.

All maneuvers were tracked by ground-based tracking systems to provide accurate three-dimensional position information.

Conclusions:

- o The test results do not support a decrease in the width of the primary surface for straight-in approaches to, and straight-out departures from, VFR heliports. These tests were conducted without

obstacles. Undoubtedly, the presence of obstacles would have influenced pilot performance by providing visual cues. Nevertheless, it is not certain that these visual cues would have decreased the spread of the data to the point that it would justify narrowing the width of the primary surface.

- o Mean and standard deviations of the altitude errors are similar for all three elevation angles. The altitude errors indicate that pilots flew consistently above the desired surface for these angles, with the steepest angle showing the higher offsets.
- o Although pilot performance increased with increases in the approach angle being flown, these test results do not support an increase in the 7.125 degree slope of the primary approach surface. Undoubtedly, when the intended approach angle is 7.125 degrees, the presence of objects just below the 8-to-1 surface will cause pilots to fly a higher approach angle in response. The acceptability of an 8-degree approach angle does not justify an 8-degree approach surface. There is a need for a safety margin between the approach angle and the approach surface to account for the dispersion of pilot performance.
- o Steeper approaches and departures can be safely flown when sufficient aircraft power reserve is available. However, sufficient reserve may not be available for all aircraft utilizing every public heliport.
- o Departure results indicate that pilots consistently operated well above the selected departure reference angle. However, pilots deviated from the intended departure path due to their perception there would be possible interference with runway traffic. No reduction in pilot performance was observed for increasing departure angles.
- o Pilots perceived the three straight-out departure maneuvers as adequate, but they favored the two shallower angles, 7.125 degrees and 10 degrees, more than the 12-degree angle. The shallower angles were perceived as somewhat safer and more controllable, but not to a significant extent. However, when given a choice, pilots consistently flew steeper departure angles than defined by the current surface.
- o Even though this test was not structured to define all aspects of airspace requirements for curved approaches and departures, similar statements can be made for the curved procedures. Airspeed profiles used in this test were above what pilots preferred to fly. This resulted in test data that indicated the lateral dimensions of airspace required for curved approaches and departures should be larger than required for straight-in approaches and departures. Pilots strongly expressed a preference for the flexibility that results from curved approach and departure paths, indicating the

necessity for further testing to define curved approach and departure airspace requirements.

- o When given a choice, pilots continually initiated approaches above the current 7.125 degree surface.
- o Pilots accurately tracked their selected glidepath profiles.
- o Pilots perceived all three angles for both straight-in and curved approaches as adequate. They favored the shallow 7.125 degree angle. Their perception indicates that steeper angles increased their workload and reduced safety and control margins. In measured deviations, their performance for the steeper angle approaches was as good as or better than performance for the shallower angles.

Additional Comments/Recommendations:

- o A reduction in the VFR airspace for either heliport approaches or departures is not recommended.
- o Discussion with subject pilots and industry officials has indicated there is tremendous interest in the flexibility provided by curved approaches and departures. However, this test was not structured to define all aspects of airspace requirements for curved approaches and departures. Additional testing is required to define the minimum airspace for such procedures. Of particular interest is the minimum length of the final straight segment in a curved approach to, or departure from, a heliport and the lateral dispersion throughout the procedure.

2.10 HELICOPTER VISUAL SEGMENT APPROACH LIGHTING SYSTEM (HALS)

Report No: DOT/FAA/CT-TN89/21

Report Date: March 1989

Authors: Barry Billman and Scott Shollenberger

Performing Organization: FAA Technical Center

Issue: Operational

Goals:

- o Obtain pilot performance and subjective pilot data on the helicopter visual segment approach lighting system.
- o Identify performance measures that correlate with the pilot's ability to visually acquire a HALS-equipped heliport.

Methodology: Tests were conducted at the FAA National Concepts Development and Demonstration Heliport in Atlantic City, New Jersey. The flight test vehicle was a Department of the Army UH-1H helicopter. The aircraft was equipped with an HSI and DME/P for distance and DH

information. The approach aid was a Hazeltine Corporation Model 2400 MLS.

The heliport approach lighting system consisted of the basic IFR heliport lighting system and a centerline HALS. In addition, a visual glideslope indicator (VGSI) was used. The VGSI is set for guidance at a 6-degree elevation angle.

Four different lighting combinations were tested: the basic IFR heliport lighting system, the basic IFR system augmented with VGSI, the basic IFR system augmented with HALS, and the basic IFR system augmented with both HALS and VGSI.

The basic IFR lighting system consisted of perimeter lights around the final approach and take-off area, wing light bars, and edge light bars. In-pad centerline touchdown lights were also included. The centerline HALS consisted of a series of approach light bars spaced at 100-foot intervals for 800 feet. Although the HALS was reconfigurable, only the described configuration was evaluated during the test.

Approach profiles flown replicated the following elevation angles and DH/visibility combinations.

	ELEVATION ANGLE (degrees)		
	<u>3.0</u>	<u>4.5</u>	<u>6.0</u>
DH (height above heliport)	200	250	250
Visibility (statute miles)	3/4	1/2	1/2

The subject pilots who participated in this test came from industry, the FAA, and the military. They were current and qualified in the UH-1H, and their helicopter flight time ranged from 600 hours to more than 12,000 hours, with time in type ranging from 75 hours to 5,100 hours.

A total of 12 data collection flights were completed.

Conclusions: Several conclusions can be made based on subjective and objective data analyses of the HALS test results.

- o The HALS can support precision approaches to heliports when the approach minima contained in the draft Heliport TERPS document are used. When HALS was used, all approaches were successfully completed even when guidance was significantly displaced from the nominal approach centerline DH.

(Author's note - The referenced "draft Heliport TERPS document" was published by the FAA on 9/27/91 as FAA Order 8260.37.)

- o All subject pilots rated the approach light system characteristics significantly better when the VGSI was available. Although there

was no detectable improvement in pilot vertical tracking performance with the addition of the VGSI, all subjects rated the workload lower and deceleration guidance better when it was available. The VGSI was not optimally adjusted to enhance pilot performance for these tests.

- On two separate occasions, the subject pilot was unable to complete approaches to the heliport, resulting in missed approaches. In both cases, the HALS was not available for the approach. The critical nature of the missed approaches cannot be overemphasized. The pilot elected to miss well inside DH, resulting in a flight path that placed the aircraft well below the 20:1 missed approach surface for a significant period.
- The mean pilot responses for deceleration cuing and workload characteristics indicate pilots would only rarely use an approach system if HALS were not available. Analysis of subjective comments and performance data indicates that HALS provides more benefits than just extending the range to ground contact. These benefits could not be quantified. However, decelerations were more constant and were initiated sooner when HALS was available.
- A question that must be addressed is what are the appropriate minima when HALS is not available? This test was not structured to answer this question. Testing to address this issue requires that the approach minima be a test variable rather than a fixed condition as it was in this test.
- The benefits from a vertical guidance aid such as the VGSI must be investigated more fully. This test was not designed to optimize the performance gains that are possible when a lighting aid is present to provide vertical guidance.

Additional Recommendations:

- Release the heliport MLS TERPS with minima as published if a HALS similar to the one evaluated in these tests is available. Minima without HALS should be very conservative (i.e., 400 feet and 1 mile or greater) until further testing can be accomplished.
- Design and conduct a series of tests to determine the appropriate approach minima for precision instrument approaches to heliports when an approach light system is not available. Also, testing to identify optimal VGSI beam widths and location on the heliport should be conducted.
- Previous heliport MLS testing had identified the fact that the pilot had the least difficulty with deceleration and landing when the elevation antenna was located well in front of the landing area. With deceleration difficulties noted in these tests, that work should be revisited and consideration given to relocation of the elevation antenna at heliports.

- The HALS configuration that was tested resulted from considerable preliminary development efforts conducted over several years. The length of the system can be shortened; however, any reduction in length would result in an increase in minimums. Conversely, any lengthening of the HALS would result in a decrease in minimums but with a real estate penalty. Therefore, analysts recommend the basic HALS configuration used in these tests be considered standard and individual nonstandard sites be tailored accordingly.
- Development of advanced instrument procedures for use at heliports and vertiports should continue. Several topics that should be addressed include deceleration below V_{mini} airspeeds before DH, range/range rate biasing of the flight director pitch cue, and pilot performance when manually flying flight director-aided approaches to heliports.
- Expanded testing to augment UH-1 data with data from the S-76 should be considered.

2.11 FLIGHT TEST INVESTIGATION OF FLIGHT DIRECTOR AND AUTOPILOT FUNCTIONS FOR HELICOPTER DECELERATING INSTRUMENT APPROACHES

Report No: DOT/FAA/CT-TN89/54

Report Date: November 1989

Authors: Roger H. Hoh, Stewart Baillie, and Stan Kereliuk

Performing Organizations: Systems Technology, Inc., National Aeronautical Establishment (Canada), Systems Control Technology, Inc.

Issue: Certification

Goals:

- Determine limiting factors for crosswind regulation.
- Determine minimum acceptable combinations of flight director and autopilot functions for decelerating approaches.
- Determine necessary characteristics for the collective flight director.

Methodology: An in-flight simulation was performed to investigate the impact on handling qualities and certification of various issues associated with low minima decelerating flight-directed IFR approaches.

Five pilots (two helicopter certification pilots, an operational pilot from the FAA, one certification pilot from Transport Canada, and a research pilot from Canada's National Aeronautical Establishment (NAE)) participated in the experiment. The project utilized the NAE Bell 205 Airborne Simulator and approximately 180 approaches were evaluated.

Decelerating approaches commenced at 60 knots decelerating to 20 knots with a simulated DH of 50 feet. The task involved tracking a 6-degree glideslope from an initial altitude of 800 feet above ground level.

Conclusions:

- o Certification of helicopters for decelerating approaches to a 50-foot DH and 20 knots airspeed is feasible.

The more detailed conclusions based on the results of this program are summarized below.

- o A two-axis flight director (pitch and roll) with raw data collective is acceptable.
- o All tested methods of crosswind regulation were acceptable for constant speed or decelerating approaches, i.e.:
 1. wing-low, as long as the required lateral acceleration does not exceed approximately .07g.
 2. turn-coordination (crab), if the field-of-view is not limiting - depends on the specific aircraft cockpit geometry, V_{mini}, and the maximum certificated crosswind, and
 3. blend from turn-coordination to wing-low during deceleration.
- o Errors as large as 25 feet were common for glideslope tracking under manual control, with or without a flight director. These were reduced to 12.5 feet if the vertical axis was fully coupled. The maximum tracking errors in localizer and airspeed were on the order of 10 feet and 5 knots for flight-directed and coupled approaches.
- o The lowest workload occurred for fully coupled approaches.
- o Coupling only one axis improved the subjective opinion of workload and flying qualities slightly compared to fully manual approaches.
- o There is a need to define the dimensions of the approach corridor and decision height window, as it has a significant impact on pilot workload for manual flight-directed approaches.

2.12 DECISION HEIGHT WINDOWS FOR DECELERATING APPROACHES IN HELICOPTER - PILOT/VEHICLE FACTORS AND LIMITATIONS

Report No: DOT/FAA/CT-90/14

Report Date: June 1990

Authors: Roger H. Hoh, Joseph J. Traybar, Stewart W. Baillie, and Stan Kereciuk

Performing Organizations: Hoh Aeronautics, Inc., National Research Council (NRC) (Canada)

Issues: Operational/Technical

Goals:

- o Determine the basic limitations of pilot plus rotorcraft in making the transition from a very low DH to a steady hover over the helipad.
- o Define a DH window that exists at breakout to allow a safe transition to hover.
- o Evaluate the effect of poor visibility during the visual segment of an approach.

Methodology: Flight tests were conducted with the NRC variable stability Bell 205A configured with conventional cyclic stick and collective cockpit controllers.

The initial phase of testing was to determine flight path angle and velocity characteristics of the 205A to allow estimates of the DH window based on an effective flight path angle.

Test pilots flew a precision approach to a 50-foot DH in simulated IMC, and completed the approach to a hover over the helipad. IMC was simulated by electronically fogged goggles.

A series of runs were flown when the fogging level was set so the evaluator could barely make out the pad at DH and the goggles did not clear. These runs were included to evaluate the effect of poor visibility during the visual segment.

The focus of the evaluations was on the segment from DH to hover.

Most of the tests focused on a 9-degree glideslope, although some approaches were flown at 6 degrees to investigate glideslope variation.

Conclusions: Based on the flight test program, initial estimates of the DH window are summarized below.

- o The coordinates of the DH window are defined by groundspeed at DH on the horizontal axis, and glideslope error at DH on the vertical axis.
- o The upper and right boundaries of the DH window are based on helicopter performance limitations.
- o The left boundary of the DH window is based on rotorcraft handling at very low airspeeds.

- The bottom boundary of the DH window is based on obstruction avoidance and pad visibility.
- The right boundary of the DH window is based on the minimum usable torque and related maximum acceptable pitch attitude during deceleration.
- The upper boundary of the DH window is based on the maximum aerodynamic flight path angle that can be flown at very low airspeeds.
- Simulation of poor visual cuing after breakout emphasized the need for margin from rotorcraft performance limits for both the right and upper DH windows.
- The dimensions of the DH window are directly proportional to the ratio of the maximum usable aerodynamic flight path angle to the glideslope angle.

Additional Comments: An attempt was made to gain insight into the effect of poor visibility after breakout by leaving the goggles fogged at some intermediate level. However, this simulation was felt to be unrealistic due to lack of graininess versus altitude cues, and lack of helipad lighting and visual approach aids which would be present in operational use.

2.13 RESULTS OF FLIGHT TESTS TO INVESTIGATE CIVIL CERTIFICATION OF SIDESTICK CONTROLLERS FOR HELICOPTERS

Report No: DOT/FAA/CT-TN90/TBD*

Report Date: July 1990

* Authors Note: This report is in the final coordination phase within ACD-230 and has not been assigned a report number. The report parallels the National Research Council's (NRC) 1990 report IAR-AN-67 (NRC No. 32133) entitled "An Investigation into the Use of Side-Arm Control for Civil Rotorcraft Applications," (S.W. Baillie, S. Kereliuk).

Author: Roger H. Hoh

Performing Organizations: FAA and the Canadian National Aeronautical Establishment/National Research Council (NAE/NRC)

Issue: Certification

Goal: Compare test results of two sidestick controllers with a conventional rotorcraft cyclic, collective, and pedal controller configuration.

Methodology: Flights tests were conducted in a variable stability Bell 205A with a baseline configuration consisting of the usual cyclic, collective, and pedals found in all helicopters.

Two sidesticks were tested, one with a moderate amount of travel (sidestick A) and one with very limited travel (sidestick B).

Controller configurations tested:

1. conventional cyclic stick, collective, and pedals;
2. sidesticks A and B with pitch and roll active, and yaw and heave disconnected; pilot flew yaw and heave with standard pedals and collective, respectively;
3. sidesticks A and B with pitch, roll, and collective active, and yaw disconnected; pilot flew yaw with standard pedals; and
4. sidesticks A and B with pitch, roll, and yaw active, and collective disconnected; pilot flew heave with standard collective.

Pilots were introduced to the full (4+0) sidestick at the beginning and again at the end of the tests, i.e., after they had between 10 and 12 hours of sidestick experience.

Finally, each pilot was given an opportunity to fly the conventional controls at the end of the tests to allow a direct comparison with the full (4+0) sidestick after a reasonable amount of sidestick training had been completed.

Conclusions:

- o After about 10 to 12 hours of training, pilot ratings for a well-designed sidestick in the four-, three-, and two-axis configurations are the same as for conventional controls.
- o There is some evidence that autorotation could be a problem for the 4-axis sidestick.
- o The pirouette maneuver exposed sidestick problems that were not apparent with conventional controls. This may have been the result of limited sidestick training. Increased pilot workload associated with multiple axis control with one hand, i.e., the maneuver requires coordination in all three axes, could require more training than was available.
- o The ratings for sidestick A were significantly degraded due to the change in breakout and gradient from nominal design specifications.

Additional Comment: Certification flight testing of sidesticks should focus on multi-axis tasks, the effect of changes in breakout and gradient, maneuvering in high winds, and autorotation.

3.0 SCOPE OF TERMINAL AREA PROCEDURAL DEVELOPMENT

Terminal operational procedural development is by necessity a very long, intensive effort involving several FAA offices, including AVN, AFS, and ACT, and encompassing most if not all of the parameters discussed below.

3.1 PHYSICAL AND OPERATIONAL FACTORS

Aircraft

- o Vertical takeoff and landing (VTOL) - helicopters, tiltrotors, and other advanced rotorcraft.
- o Short takeoff and landing (STOL) - special performance fixed-wing and rotorcraft.
- o Conventional takeoff and landing (CTOL) - all other fixed-wing aircraft.

Approach Geometry

- o Straight-in (ILS, MLS) - precision/nonprecision approach
- o Steep angle - approach angles greater than 3 degrees up to the capability of the aircraft
- o Approach course - angular and parallel
- o MLS segmented
- o MLS curved path
- o Area navigation (RNAV)

Operations Other Than Approach

- o Departures
- o Terminal area maneuvering (turn reversals, holding)
- o Missed approach based on MLS guidance
- o Missed approach turning radius based on airspeed
- o Missed approach climb capability (in relation to missed approach surfaces and airspeeds flown)

Landing Environment

- o Heliports (collocated system, highly constrained landing area)

- o Vertiports (larger facilities than heliports, less constrained landing area, will accomodate large rotorcraft)
- o Secondary runways (not primary to ground system installation)
- o Short precision runways (VTOL, STOL)
- o Helicopter operations at airports (to runways and points other than active runways)

3.2 PROCEDURE DEVELOPMENT

Development of terminal operational procedures incorporates investigations in three categories: (1) obstacle clearance, (2) procedural design, and (3) operating minima. Each category is then further defined into specific subject areas. Each area must be analyzed to ensure that both aircraft and pilot are physically capable of performing the maneuvers and that the procedures can be performed safely.

At a minimum, the subject areas below must be evaluated.

- (1) Obstacle Clearance
 - o Airspace definition
 - o Obstacle type (natural or man-made)
 - o Acceptable risk
 - o Segments
 - a. initial, intermediate, and final segments
 - b. missed approach segments
 - c. departures
 - d. terminal area maneuvering (turn reversals, holding)
 - e. en route
- (2) Procedural Design
 - o 3-dimensional
 - o operational considerations
 - o segment lengths
 - o descent gradients
 - o turn radii
 - o speed categories
 - o holding patterns
 - o step-down fixes
 - o simultaneous operations
 - o geographical/facility constraints
 - o procedure construction
 - o peculiar applications, i.e.,
 - a. special performance aircraft
 - b. unusual geographical locations
- (3) Operating minima
 - o visibility
 - o DH (precision approach)

- o MDA (nonprecision approach)
- o adjustments, i.e.,
 - a. lighting
 - b. remote altimeter
 - c. precipitous terrain
 - d. aircraft characteristics

3.3 PROCEDURAL CONCEPTS

In the development of terminal instrument procedures, there are a number of underlying concepts and assumptions that apply to the procedure development. Many of these procedural concepts are identified in the following subject areas.

Comprehensive Criteria

- o Acceptable level of safety for obstacle clearance
- o Instrument-rated pilot of average skill

Navigation Systems

- o Operate within system tolerance
- o Ground (VOR, nondirectional beacon (NDB), LORAN, DME)
- o Landing (ILS, MLS)
- o Airborne (RNAV, inertial navigation system (INS), MLS, ILS, LORAN, flight management system (FMS), GPS, VOR, NDB, DME)

All Systems Operational

- o No engines or other aircraft system malfunctions
- o No airborne navigation malfunctions
- o No ground navigation malfunctions

Procedural Design

- o Nominal aircraft performance/maneuvering
- o Normal cockpit procedures/operating techniques

Airspace

- o Minimum for adequate safety to fly system - used for:
 - a. manually flown raw data,
 - b. flight director aided, and
 - c. auto-pilot coupled.

4.0 FUTURE REQUIREMENTS

Table 2 contains a list of future rotorcraft R&D requirements that must eventually be addressed. These are tentative requirements awaiting validation.

4.1 ISSUE - EQUIPMENT/CREW REQUIREMENTS

Purpose - Define equipment/crew requirements in general terms for complex, steep angle, and decelerating approaches.

- a. Establish acceptable FTE and height loss at DH for any aircraft.
- b. Provide FAA/industry with a baseline for aircraft requirements.
- c. Separate actions and discussions from CAT I, II, and III approach terminology/concept by name and approach concept, such as glideslope angles and heliport versus airport. Establish heliport/vertiport equivalents of operational categories.
- d. Develop lower minima for rotorcraft, e.g., 50 feet over displaced threshold, or develop approach categories for rotorcraft.

4.2 ISSUE - STEEP-ANGLE CRITERIA FOR FLIGHT TECHNICAL ERROR (FTE) AND DECISION HEIGHT (DH) ALTITUDE LOSS

Purpose - Define in generic terms what is an acceptable FTE/altitude loss at DH for steep-angle approaches by vertical flight aircraft.

4.3 ISSUE - AIR CARRIER CERTIFICATION REQUIREMENTS

Purpose - Establish civil advanced rotorcraft aircrew qualification, training, testing, and certification requirements. Anticipate civil tiltrotor and other related technical developments that will likely expand vertical flight into significant major air carrier environments.

4.4 ISSUE - LOWER AIRPORT MINIMA FOR ROTORCRAFT/TILTROTORs

Purpose - Develop lower minima for rotorcraft, e.g., 50 feet over displaced threshold, or develop approach categories for specially equipped rotorcraft (e.g., automatic level-off).

4.5 ISSUE - VERTIPORT DIMENSIONAL REQUIREMENTS

Purpose

- a. Validate vertiport design parameters, dimensional requirements identified in Vertiport Design Advisory Circular (AC 150/5390-3).

TABLE 2 FUTURE ISSUES AND TEST OBJECTIVES

ISSUE	OBJECTIVE (S)
Equipment/crew requirements	Establish equipment requirements and crew qualification requirements for complex approaches, i.e., steep and decelerating.
Steep angle criteria	Define acceptable altitude loss at DH and acceptable FTE for steep-angle approaches.
Certification requirements	Establish air carrier aircrew qualification, training, testing, and certification requirements.
Lower airport minima for rotorcraft	Develop lower and/or new low approach minima for rotorcraft.
Vertiport requirements	Validate vertiport design parameters.
Vertiport takeoff and landing size requirements	Determine takeoff and landing profiles for Category A and B operations.
Vertiport/heliport lighting	Determine approach lighting alternatives.
Approach trapezoid size reduction	Reduce present 1,000 foot width to 300 foot (Cat II and III) equivalents.
Reduce size of missed approach trapezoid	Conduct experimental testing (simulators) using autopilots, flight directors, etc.
Glidepath optimization	Evaluate early turn, turn radius, and climb capability from low airspeed.
Route structure development	Determine glideslope angle and minimum clearance trapezoid for glideslopes up to 25 degrees.
	Determine degradation of MLS AZ/EL accuracy for these angles.
	Develop route structure guidelines to support rotorcraft/tiltrotor.

TABLE 2 FUTURE ISSUES AND TEST OBJECTIVES (Continued)

ISSUE	OBJECTIVE (S)
Vertical letdown	Determine feasibility of an instrument approach to an acceptable altitude and complete a vertical descent and vertical departure.
Validate the missed approach 4,000 foot turning radius and climb gradients	Test turning missed approaches at 60, 90, and 120 knots. Analyze turn radii and climb gradients.
Vertiport marking	Determine vertiport marking requirements.
Supplementary emergency power	Determine acceptability of lightweight, inexpensive, high-power, short-lived, power plants for OEI operations.
Visionics (synthetic vision)	Identify cost, complexity, weight, safety, and certification tradeoffs for electronic vision devices

- b. Determine operating parameters and their impact on design standards (takeoff/landing area, parking, taxiway) both at vertiports and airports.
- c. Determine adequacy of VFR proposed airspace (approach/departure) to support civil tiltrotor.
- d. Conduct evaluations of operations in proximity to equipment, people, baggage, etc.
- e. Simulate worst case approach environment with obstructions.

What level of safety should be used for visual approaches and departures since none of the current target levels of safety lend themselves to VFR vertiport airspace?

4.6 ISSUE - VERTIPORT TAKEOFF, REJECTED TAKEOFF, DEGRADED TAKEOFF (OEI) AND LANDING SIZE REQUIREMENTS

Purpose - Determine when additional takeoff area is required for vertiports/heliports. How much? Consider differences between Category A and B aircraft operations (transport, corporate, and private), and takeoff and landing profiles for both types of operations.

4.7 ISSUE - VERTIPORT/HELIPORT LIGHTING

Purpose

- a. Determine alternatives to approach lighting. While lighting has been determined to be required for both deceleration and alignment, alternatives must be found and investigated to address these requirements.
- b. Conduct "no approach lights" (HALS) testing for minimums adjustment.

4.8 ISSUE - APPROACH TRAPEZOID SIZE REDUCTION

Purpose

- a. Determine how to reduce area width. Goal is to reduce present 1,000 foot width down to 300 foot goal (Category II and Category III equivalents).
- b. Conduct experimental testing (simulators and flight test vehicles) using autopilots, flight directors, specialized training, other equipment, new presentations, ground system enhancements, new ground systems, airborne equipment development, etc. (visionics, infrared, specialized lighting, etc.).

- c. Survey users' capabilities and wishes: what do they want? How would they pay for it? What minimums would make the cost worthwhile?

4.9 ISSUE - MISSED APPROACH REDUCED TRAPEZOID SIZE TO ADJOIN FINAL APPROACH TRAPEZOID

Purpose

- a. Evaluate early turn situations.
- b. Quantify missed approach splay (positive course guidance).
- c. Test the missed approach turn radius and climb capabilities in relation to the 20:1 missed approach surface.
- d. Determine climb capability from low airspeed (less than 30 knots).
- e. Evaluate OEI situations.

4.10 ISSUE - GLIDE PATH OPTIMIZATION

Purpose

- a. Determine glideslope angle and associated minimum clearance trapezoid for glideslopes up to 25 degrees, e.g., 3, 6, 9, 12, 15, 20, 25 degrees; test 7-, 8-, and 10-degree slopes with raw data single pilot approaches and 15-knot tailwind, using higher levels of avionics/training.
- b. Determine degradation of MLS AZ/EL accuracy for these angles. Also consider 30-, 45-, 60-, 75-, and 90-degree segmented approaches using up to a 25-degree glideslope from a maximum of approximately 300-feet altitude. (Probably using constant rate of descent and slowing airspeed in each segment.)

Note: The current IFR fleet of helicopters is certificated up to a 4-degree glidepath.

4.11 ISSUE - ROUTE STRUCTURE DEVELOPMENT

Purpose - Develop route structure guidelines to support rotorcraft/tiltrotor. What route structure (special, current, mix, etc.) is necessary to support these operations? Communications, navigation, and surveillance (CNS) requirements?

4.12 ISSUE - VERTICAL LETDOWN

Purpose

- a. Determine the feasibility of an instrument approach to determine and arrive at an acceptable vertical altitude (100, 300, 500 foot?) and complete a vertical descent and vertical departure.
- b. Determine the performance capability (power requirements).
- c. Evaluate the feasibility of vertical letdowns on instruments.

4.13 ISSUE - VALIDATE THE MISSED APPROACH 4,000 FOOT TURNING RADIUS AND CLIMB GRADIENTS

Purpose

- a. Test turning missed approaches at 60, 90, and 120 knots.
- b. Analyze the turning radii and the climb gradients.
- c. Analyze start-of-climb distance from DH, height loss, and turn radius as a function of airspeed (60/90/120 knots).
- d. Verify climb performance in relation to the 20:1 slope.
- e. Collect data regarding tail winds.
- f. Study the 60-knot approach speed to determine if there are any problems associated with it.
- g. Verify how pilots are being trained to fly IFR missed approaches, with particular interest on speed.
- h. Test S-76A with single pilot flight director and compare results with earlier raw data flight tests.
- i. Determine turning radii and climb gradients on missed approaches. (Note: procedures are now based on 4,000 feet.)
- j. Develop flight procedures. Determine whether a speed restriction is required.

4.14 ISSUE - VERTIPORT MARKINGS

Purpose - Determine vertiport marking requirements. Review research work done to date on heliport markings. If necessary, test vertiport markings.

4.15 ISSUE - SUPPLEMENTARY EMERGENCY POWER FOR ONE-ENGINE INOPERATIVE (OEI) OPERATIONS

Purpose - Determine the acceptability of lightweight, inexpensive, high power, relatively short-lived, power plants that can be started for the category "A" takeoff and landing flight phase and then be shut down for cruise. The objective is to improve takeoff/landing performance for passenger operations (category "A") with a minimum weight and cost penalty. Determine its feasibility and what type of regulatory changes would be needed.

4.16 ISSUE - VISIONICS (SYNTHETIC VISION)

Purpose - Identify cost, complexity, weight, safety, certification tradeoffs for electronic visual devices (forward looking infrared (FLIR)), night vision goggles (NVGs), low-light television (LLLTV), etc.). Follow up with hardware tests, if the concepts show potential.

LIST OF ACRONYMS

AC	Advisory Circular
ACN	FAA Technical Center's Engineering, Test, and Evaluation Service
AFCS	Automatic Flight Control System
AFS	Flight Standards Service
ARA	Airborne Radar Approach
ARD	Research and Development Service
ASRP	Approach Surface Reference Point
ATC	Air Traffic Control
AVN	Aviation Standards National Field Office
AZ	Azimuth
CEP	Circular Error Probability
CNS	Communications, Navigation, and Surveillance
CTOL	Conventional Takeoff and Landing
DG	Directional Gyro
DH	Decision Height
DME	Distance Measuring Equipment
DME/P	Distance Measuring Equipment/Precision
DOD	Department of Defense
DWFAP	Downwind Final Approach Point
EL	Elevation
FAA	Federal Aviation Administration
FLIR	Forward Looking Infrared
FMS	Flight Management System
FRP	Federal Radionavigation Plan
FTE	Flight Technical Error
GPS	Global Positioning System
GRI	Group Repetition Interval
HALS	Heliport Approach Lighting System
HSI	Horizontal Situation Indicator
IFR	Instrument Flight Rules
ILS	Instrument Landing System
IMC	Instrument Meteorological Conditions
INS	Inertial Navigation System
LLLTV	Low-Light Television
LORAN-C	Long Range Navigation
MAP	Missed Approach Point
MDA	Minimum Descent Altitudes
MLS	Microwave Landing System
NAE	National Aeronautical Establishment
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
NAVSTAR	Navigation Satellite Timing and Training
NDB	Nondirectional Beacon
NM	Nautical Miles
NRC	National Research Council (Canada)
NVG	Night Vision Goggles
OEI	One-Engine Inoperative
R&D	Research and Development
RFI	Radio Frequency Interference

RFTE	Range Flight Technical Error
RNAV	Radio Navigation
RSE	Radar System Error
SEL	Selected Elevation Angle
STOL	Short Takeoff and Landing
TERPS	Terminal Instrument Procedures
TSCT	Total System Crosstrack
UERE	User Equivalent Range Error
VFR	Visual Flight Rules
VFTE	Vertical Flight Technical Error
VGSI	Visual Glideslope Indicator
VNAV	Vertical Navigation
VOR	Very High Frequency Omnidirectional Radio Range
VTOL	Vertical Takeoff and Landing